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AVERAGE MULTIPOLARITY OF CONTINUUM TRANSITIONS IN NUCLEI AT HIGH ANGULAR MOMENTUM

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The multipolarity of continuum transitions deexciting high-spin states has been deduced from measured conversion coefficients. The investigated ^{146}Nd(^{20}Ne, 4n or 5n) ^{162,161}Yb reactions were selected by gating on discrete lines. The average multipolarity gradually changes from E2 at 0.5 MeV to E1 above 1.5 MeV.

The use of heavy-ion beams has given impetus to studies of nuclear structure at high angular momenta. The deexcitation of states with spin $I \geqslant 20$ is nowadays investigated with spectroscopical methods adapted to this particular field. The understanding of the deexcitation mechanisms for high-spin states is growing, but there remains a great interest in new observable features of the continuum [1–3].

Recently, the average multipolarity was measured for transitions in the continuum following the ^{160}Gd(^{4}He, 4n) ^{160}Dy reaction [4]. In the "statistical region" [3] above 1.5 MeV a predominant E1 character was found. At lower energies, for the so-called "yrast transitions", the expected E2 dominance became visible. However, the (^{4}He, 4n) reaction yields a compound system with only a moderately high angular momentum. The object of the measurements reported here is to increase the maximum spin significantly in order to respond to current interest in nuclear behaviour near the upper part of the yrast curve.

The multipolarity of transitions following the ^{146}Nd(^{20}Ne, 4n or 5n) ^{162,161}Yb reactions was studied by simultaneous observation of conversion electrons with a mini-orange spectrometer [5] and γ-rays with a NaI(Tl) detector. Both the electron and γ-ray spectra were measured in coincidence with discrete transitions from the ground-state band in ^{162}Yb and the decoupled band in ^{161}Yb. These gating transitions were observed by a Ge(Li) detector ("identifier"). The mini-orange spectrometer, placed at 135° with respect to the ^{20}Ne beam, covered both yrast and statistical transitions between 0.2 and 2.3 MeV by using eight magnet settings. The Si(Li) detector of this spectrometer (thickness: 5 mm) could stop electrons of energies up to 2.5 MeV. The NaI(Tl) detector (76 mm × 76 mm) was placed at 45°, 60 cm from the target. At this distance the minor contribution of neutrons to the NaI(Tl) spectrum could be separated from prompt γ-rays by difference in time of flight. The Ge(Li) detector (60 cm^3) was placed at 135°, 7 cm from the target, symmetrically with respect to the Si(Li) and NaI(Tl) detectors to avoid angular correlation effects. The targets were 1.6 mg/cm^2 foils of ^{146}Nd (97%) on a thin Al frame (0.3 mm) with a central hole of 10 mm

× 15 mm. The ^{20}Ne beam from the CYCLONE cyclotron at Louvain-la-Neuve had an energy of 105 MeV. Energy and time signals from the three detectors were stored event-by-event on magnetic tape. Net electron and γ-ray coincidence spectra were obtained by off-line analysis with appropriate subtractions of random events and of background and continuum contributions under the gating peaks in the "identifier" spectra.

In the investigation of continuum electron spectra, a study of the background is of particular importance. The main part is due to γ-rays penetrating the central absorber of the mini-orange or producing electrons in the target region and in the surfaces of the magnets. Electrons backscattered by the Si(Li) detector play a minor role, due to the narrow transmission curves [6]. Neutrons have no significant contribution, while positrons are not transmitted by the toroidal mini-orange field. The various background components were studied in detail. Numerical estimates were supplemented by measurements with a thin ^{56}Co source in the same mounting arrangement as the target. Final values for the background contribution were derived from direct in-beam measurements using the so-called "withdrawn magnets technique" [4,6]; they varied from 25% at 1 MeV to 70% at 2.3 MeV. The NaI(Tl) spectra were unfolded with a computer code interpolating between a set of response curves measured with sources in the target position. Special attention was paid to the γ-ray spectrum below 0.7 MeV, where numerous discrete lines must be properly separated from the underlying continuum. Therefore, in these low-energy measurements the NaI(Tl) detector was replaced by a Ge(Li) detector in spite of its less favourable response function and, consequently, larger errors introduced by the unfolding procedure. Examples of electron and unfolded γ-ray spectra gated by discrete transitions in ^{162}Yb or ^{161}Yb are shown in fig. 1.

At nine different energies a total conversion coefficient α_T for the 4n-reaction was deduced (circles in fig. 2). Table 1 includes also 5n-data. The uncertainties originate from counting and systematic errors. Above 1.6 MeV the number of electrons is close to the amount expected for a pure E1 multipolarity. This result agrees with that obtained for the (^{4}He, 4n) reaction [4] and indicates the essentially E1 character of the statistical deexcitation process for nuclei with mass $A \approx 160$. From the four highest-energy points we conclude with a 90% confidence level that there is

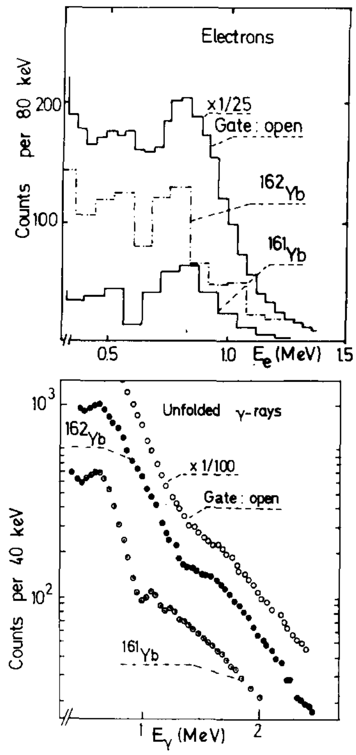

Fig. 1. Spectra of conversion electrons (upper curve 40 keV bins, others 80 keV) and unfolded γ-rays (40 keV bins) coincident with discrete transitions in ^{162}Yb, ^{161}Yb and with a broad gate (150–1500 keV). The electron spectra reflect the transmission curve through peaking around 0.85 MeV.

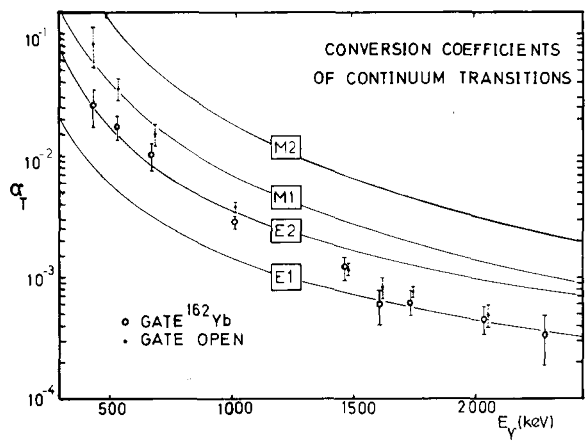

Fig. 2. Measured conversion coefficients α_T for the 4n-reaction (circles) compared with theoretical E1, E2 and M1 values (curves) and with "pseudo"-coefficients obtained with a broad gate setting (dots). The mean-energy values correspond to various mini-orange settings, each covering a typical energy width of 30%.

Table 1
Total conversion coefficients α_T for ^{162}Yb and ^{161}Yb, and "pseudo"-coefficients obtained with a broad gate setting (150–1500 keV), compared with theoretical values.

E_γ (keV)	(^{20}Ne, 4n) ^{162}Yb (×10^{-4})	(^{20}Ne, 5n)^{161}Yb (×10^{-4})	Broad gate (×10^{-4})	Theoretical [9]		
				E1	E2	M1
440	260 ±90	–	820 ±300	80	250	570
540	180 ±45	–	360 ±70	50	145	340
680	100 ±25	–	150 ±30	31	72	180
1020	29 ±4	22 ±7	38 ±5	14	35	70
1470	12 ±3	9 ±5	11.8 ±1.3	7.6	18	27
1610	6.0 ±1.9	9 ±7	8.3 ±1.7	6.4	15	24
1730	6.4 ±1.5	4 ±2	7.6 ±1.0	5.7	13	22
2140	4.6 ±1.2	6 ±3	4.9 ±1.0	4.1	9.0	12
2290	3.4 ±1.5	–	–	3.6	7.8	10

less than 26% E2 or 15% M1 contribution at 2.0 MeV, in the absence of E2 + M1 admixture. In the upper part of the yrast region ($E_\gamma \approx 1$ MeV) an increase of α_T towards the expected E2 value [3] is observed. The measurements around 0.5 MeV were inspired by recent work of Newton et al. [1] suggesting the onset of a dipole component in this part of the continuum. The experimental coefficients α_T lie slightly above the E2 curve and do not indicate preference for E1 or M1 multipolarity. An attempt was made to measure α_T at even lower energy ($E_\gamma \approx 0.25$ MeV). However, after unfolding of the γ-ray spectrum very few counts were left, making the deduction of reliable values unrealistic.

Our main findings differ from results of Westerberg et al. [7], who report a considerably larger amount of E2 (or M1) radiation above 1.5 MeV and claim M1 dominance at 0.5 MeV in the nuclei ^{164,163}Yb, also produced by (^{20}Ne, xn) reactions. With a different experimental arrangement these authors profit from high coincidence rates by not gating on discrete transitions. We prefer to accept the much lower counting rates inherent to our requirement of coincidence with discrete lines; not only to differentiate between the 4n and 5n reactions, but also to prevent the conversion coefficient to be affected by spurious events from cross talk between detectors, impurities in the target and competing reaction channels (Coulomb excitation, precompound processes, etc.). After the work of Westerberg et al. appeared, we considered it instructive to simulate their approach by replaying our magnetic tapes with a broad gate setting on the "identifier" spectrum (150–1500 keV; upper curves in fig. 1). The coefficients so obtained (dots in fig. 2) are generally higher, especially at low energies, where the reported [7] M1 dominance around 0.5 MeV is now reproduced. The electron spectra obtained with broad gates show a worse peak-to-background ratio than the spectra obtained with narrow gates. Therefore it is likely that spurious counts are illegally attributed to the electron continuum, leading to too high α_T-values. Further one should compare the γ-ray spectra obtained with narrow and broad gates, especially where the yrast region passes into the statistical region (fig. 1). All these differences demonstrate the need for narrow gate settings. Recently, Peker et al. [8] proposed that an oblate-shape region at high spin in deformed nuclei should manifest itself by the presence of low-energy stretched M1 transitions in the continuum. Based on our measurements at low energy, we state that this proposal is not yet supported by experimental evidence from multipolarity measurements.

In conclusion, the deexcitation of residual nuclei around mass 160 is characterized by E2 multipolarity of the yrast transitions and essentially E1 multipolarity in the statistical region, irrespective of their formation through light-ion (^{4}He, ref. [4]) or heavy-ion (^{20}Ne) bombardment. This indicates that the statistical deexcitation process maintains its multipolarity character in going from moderate to high angular momentum input into the nucleus.

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